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I, ANNA MAIJA MADL, ACTING TEAM LEADER EXAMINATION
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Provisional specification in connection with Application No. PP6185 for a patent
by INNOVA SOIL TECHNOLOGY PTY LTD filed on 28 September 1998.



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A. M. Madl

ANNA MAIJA MADL
ACTING TEAM LEADER
EXAMINATION SUPPORT & SALES

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PROVISIONAL SPECIFICATION

Invention Title: **Soil Remediation System**

The invention is described in the following statement:

"SOIL REMEDIATION SYSTEM"

Field of the Invention

The present invention relates to the remediation of soil contaminated with hydrocarbons, utilising thermal desorption followed by thermal oxidation.

5

Background Art

There are numerous other types of processes for remediating soils, including soil washing, in-situ air stripping, in-situ vitrification, stabilisation, vacuum extraction and solvent extraction. However, the most universally proven and efficient method for removing organics from soil is thermal desorption, which
10 together with treatment or destruction of the desorbed organics is termed thermal remediation. Hydrocarbon contaminants which are treatable with thermal remediation include:

- Volatile organic compounds (VOC) eg petrol, diesel,
- Aromatic hydrocarbons eg benzene, tars,
- 15 • Dioxins and furans,
- Semi-volatile organic compounds (SVOCs),
- Polynuclear aromatic hydrocarbons (PAHs or PNAs),
- Polychlorinated biphenyls (PCBs), and
- Pesticides (eg organochlorines such as dieldrin and aldrin).

20

Thermal remediation of contaminated soil uses heat to physically separate hydrocarbon based contaminants from feed material which may be, eg, directly recovered soils, sediments, sludges or filter cakes. The separated hydrocarbons are then combusted or thermally oxidised to produce essentially carbon dioxide and water vapour.

25

The most common process configuration involves a counter-current direct

fired desorber, but there are numerous variants. The most common alternative is the co-current desorber, which produces a hotter contaminated offgas stream. To avoid cooling these gases to enable fabric filtration, a cyclone is used to remove some of the dust prior to thermal oxidation, followed by gas cooling then fabric
5 filtration. In another variant the functions of the thermal desorber and oxidiser are combined by arranging to combust the contaminant gases within a metal jacketed combustion chamber within a rotary desorber.

United States patent 5658094 discloses an arrangement in which heat exchangers are used for preheating combustion air for a thermal desorber. In that
10 arrangement, there is described a combined (all metal) rotary device, a type of rotary kiln with internal indirect heating of both soil and combustion air, which is claimed to carry out combined thermal desorption and thermal oxidation.

The main difference between different technologies is the equipment used for thermal desorption, which may be one of four main types, the advantages and
15 disadvantages of which are summarised in Table 1 (obtained from various sources, including W.L. Troxler et al, "Treatment of non-hazardous petroleum-contaminated soils by thermal desorption technologies", Jnl of Air and Waste, Vol. 43, Nov. 1993, and W.C. Anderson, "Innovative site remediation technology", Thermal Desorption, WASTECH, 1993).

Table 1

Main Types of Thermal Remediation

	Advantages	Disadvantages
Direct fired rotary kilns	<ul style="list-style-type: none"> • High rates of heat transfer. • Smaller desorber than indirect fired. • Simplest, most robust. • Most flexible to variation in feed material and type and level of contamination. 	<ul style="list-style-type: none"> • Larger thermal oxidiser than for indirect fired. • Dilution strategies are usually required for hydrocarbon contamination levels of >4% to avoid exceeding the LEL of desorber offgases.
Indirect fired rotary kilns	<ul style="list-style-type: none"> • May allow economic recovery of hydrocarbons. • Lower dust losses from desorber. 	<ul style="list-style-type: none"> • Unsuitable for heavy contamination, especially of long chain or aromatic hydrocarbons (tars). • Larger desorber. • Higher moisture soils severely impair capacity.
Combination direct/indirect fired desorber, with integral thermal oxidiser	<ul style="list-style-type: none"> • Process simplification by using a single process step. 	<ul style="list-style-type: none"> • Inability to process large gas volumes. • Lower peak soil temperatures will prevent practical decontamination of heavily contaminated soils, especially with PAHs or PCBs. • Less suitable for high moisture soils.
Direct fired conveyors, including metal belts and screws	<ul style="list-style-type: none"> • As for indirect fired rotary kilns. • Improved control over solids residence time. 	<ul style="list-style-type: none"> • As for indirect fired rotary kilns.
Direct fired fluidised beds	<ul style="list-style-type: none"> • Highest process intensity. 	<ul style="list-style-type: none"> • Increased complexity. • Increased dust losses/recycling of dusts. • Requires fine and uniform sized material (normally less than 5mm). • Increased maintenance (abrasion).

Remediation plants may be either stationary or mobile, with the larger, stationary plants being restricted to remediation on large heavily contaminated sites (eg large integrated steelworks sites), regional clusters of contaminated sites, or under circumstances where transport of contaminated materials is economic
5 and not hazardous.

Key technical factors in thermal remediation include:

- Solids temperature and contact time.
- Soil moisture when treated.
- Actual soil hydrocarbon contaminants present.
- 10 • Other contamination, eg chlorine compounds and heavy metals.
- Extraneous rubble.

It is an object of the present invention to provide an improved method and apparatus for remediating soil contaminated with hydrocarbons that is capable in preferred embodiment of optimising energy usage and operating costs for a given
15 soil throughput, and that is preferably adaptable to treat short chain, long chain, aromatic, and polychlorinated hydrocarbons. In particular embodiments, it is further desired to minimise environmental impacts, especially greenhouse gases, NO_x and dioxin/furan emissions.

Summary of Invention

20 The invention accordingly provides, in a first aspect, a process for remediating soil contaminated with hydrocarbons, including:

desorbing the hydrocarbon contaminants from a bed of the soil by thermal desorption in a treated desorption chamber and thereafter combusting the contaminants in a thermal oxidiser,

25 wherein desorbed contaminants in gaseous form are at least in part combusted within said desorption chamber by controlled admission of air

into said chamber above said bed to effect such combustion.

In its first aspect, the invention further provides apparatus for remediating soil contaminated with hydrocarbons, including:

5 first furnace means defining a desorption chamber in which a bed of said soil may be treated to separate the hydrocarbon contaminants from the soil by thermal desorption;

second furnace means for combusting hydrocarbon contaminants by thermal oxidation;

10 means for controlled admission of air into said desorption chamber above said bed to effect in the said chamber at least partial combustion of said desorbed contaminants in gaseous form; and

means for conveying the products of said at least partial combustion to said second furnace means for further combustion therein.

15 Preferably, the desorption chamber is provided in a rotary kiln that thereby constitutes the first furnace means and is preferably inclined. The contaminated soil, which is advantageously optimally sized and prepared, is preferably admitted to an upper, cooler end of the rotary kiln at a controlled rate, and the rotation of the kiln then causes the soil to move down the inside of the kiln towards the hotter end containing a burner. The heat from the burner and other exothermic reactions
20 in the kiln heats the soil, causing it to dry and "desorb" (a term which includes without limitation evaporation, decomposition and gasification) contained hydrocarbon contaminants.

25 Preferably, the at least partial combustion of the contaminants in the desorption chamber occurs both in close proximity to the soil bed and in the hot gas stream passing along the desorber. The air admitted to effect such combustion may be injected at the burner end of the desorption chamber. The first furnace means is preferably a high velocity desorber burner which provides a

highly collimated stream of high temperature gases along the centre of the desorber.

In a second aspect, the invention provides a process for remediating soil contaminated with hydrocarbons, including:

5 desorbing the hydrocarbon contaminants from a bed of the soil by thermal desorption in a treated desorption chamber and thereafter combusting the contaminants in a thermal oxidiser;

10 wherein combustion air for said desorption chamber and said thermal oxidiser, and said desorbed contaminants prior to admission to said thermal oxidiser, are preheated by heat exchange with offgases from the thermal oxidiser.

The invention further provides, in its second aspect, apparatus for remediating soil contaminated with hydrocarbons, including:

15 first furnace means defining a desorption chamber in which a bed of said soil may be treated to separate the hydrocarbon contaminants from the soil by thermal desorption;

second furnace means for combusting hydrocarbon contaminants by thermal oxidation;

20 means for conveying combustion air to said desorption chamber and to said second furnace means, and for conveying the desorbed contaminants from the absorption chamber to the second furnace means; and

heat exchange means arranged for preheating said combustion air and said desorbed contaminants by heat exchange with offgases from the second furnace means.

25 Preferably, the heat exchange means is further arranged in a series

configuration so that said offgases preheat the combustion air first and then the desorbed contaminants.

Advantageously, the heat exchange means is directly installed in the hot gas duct at the offgas outlet end of the second furnace means for thermal oxidation, and is preferably arranged for co-current flow. The leading tube bank of the heat exchange means preferably incorporates variable tube spacing to facilitate the aforementioned direct installation (preferably without radiation shields or excess metal temperatures).

There may be an energy dump valve from the heat exchange means for venting of excess preheated air as will occur during treatment of higher contaminated soil. Preferably, the process and energy dump valve are controlled to maintain metal temperatures above 500°C, to minimise dioxin formation from PCB or salt contaminated soils, but below 700°C to minimise metal oxidation, corrosion and expansion damage. The heat exchange means may have a hot gas by-pass duct and damper system in either or both the offgas duct or by-pass duct to control hot gas flow through both the combustion air and contaminants heat exchanges.

The heat exchanger for the contaminants may have either co-current or counter current flow, and may be adapted to be made reversible depending on operating conditions.

In a third aspect, the invention provides a process for remediating soil contaminated with hydrocarbons, including:

desorbing the hydrocarbon contaminants from a bed of the soil by thermal desorption in a treated desorption chamber and thereafter combusting the contaminants in a thermal oxidiser;

wherein the separated contaminants are treated in said thermal oxidiser in at least two stages, including a combustion stage in which the contaminants are combusted with a first supply of combustion air at a substantially

adiabatic temperature in the range 900 - 1200°C, and a second stage in which a second supply of combustion air is admitted for combustion of residual compounds and for controlling the offgas outflow temperature.

The invention also provides, in this third aspect, apparatus for remediating
5 soil contaminated with hydrocarbons, including:

first furnace means defining a desorption chamber in which a bed of said soil may be treated to separate the hydrocarbon contaminants from the soil by thermal desorption;

10 second furnace means for combusting hydrocarbon contaminants by thermal oxidation;

wherein said second furnace for thermal oxidation includes at least two stages including a combustion stage in which the contaminants are combusted with a first supply of combustion air at a substantially adiabatic temperature in the range 900 - 1200°C, and a second stage in which a
15 second supply of combustion air is admitted for combustion of residual compounds and for controlling the offgas outflow temperature.

In the preferred operation of the first stage of the thermal oxidiser, preheated near stoichiometric amounts of combustion air, preheated dedusted desorber offgases, ie desorbed contaminants, and auxiliary fuel are injected,
20 preferably via a nozzle mix burner. The fuel rate and preheat to this burner is arranged to give said adiabatic flame temperature of the mixture of 900-1200°C, and thus avoids localised high temperatures and high NO_x from the use of preheated combustion air. However, the temperature is sufficient to destroy any gaseous contaminants in the desorber gases. These hot gases then pass into the
25 second zone of the thermal oxidiser where cold or preheated combustion air is injected into the hot gas stream to provide additional mixing and oxygen for combustion of residual compounds, and to control the gas inlet temperature to the heat exchangers.

The invention also extends to methods or apparatus incorporating two or more of the three disclosed aspects of the invention.

The offgas from thermal oxidation may be further treated (eg after said heat exchanges in the second aspect of the invention) by one or more modular off-gas
5 treatments according to the nature of the original contaminants, and the requirements of the soils being remediated. For low chlorine containing soils, such an off-gas treatment system may be omitted, and replaced with a short stack. For higher chlorine containing soils, where the risk of dioxin or hydrochloride containing gases is evident, a scrubber section may be used. A suitable scrubber
10 can treat most of the offgases. A small bleed of hot off-gas or preheated combustion air is allowed to by-pass the scrubber to provide reheating of the scrubbed gas stream in the stack thereby preventing drooping or visible plumes. For gases of intermediate chlorine compound content, a module comprising a cold air quenching module may be used, wherein a large volume of ambient air is
15 injected into the offgases to rapidly quench them to less than 200°C.

Brief Description of the Drawings

Figure 1 is a block flow diagram of an apparatus incorporating embodiments of all three principal aspects of the invention; and

Figure 2 is a diagram depicting combustion of desorbed contaminants in
20 the desorber kiln.

Preferred Embodiment

The illustrated system includes a pair of furnaces 20, 30, being a slightly inclined countercurrent rotary kiln 20 for effecting thermal desorption and a 2-stage thermal oxidiser 30. The off-gases 32 from thermal oxidiser 30 pass directly
25 through a 2-stage heat exchanger 40. In the first stage 42 of the series arrangement, itself consisting of a pair of sub-stage tube banks M, L, cold combustion air admitted along supply duct 41 is pre-heated for delivery to the lower, burner ends of desorber kiln 20 and oxidiser 30 by respective combustion

air ducts 43a, 43b. In the second stage 44 of heat exchanger 40, again consisting of respective sub-stage tube banks J, K, off-gases (including desorbed contaminants) recovered from the upper end of desorber kiln 20 via line 21, and cleaned and dedusted by cyclone 22 and bagfilter 23, are pre-heated for delivery
5 to the burner end of thermal oxidiser 30 via contaminant vapours supply line 45. Preheating may be to a temperature in the range 350-500°C.

Sized and otherwised prepared soils requiring remediation are transferred at a controlled rate into the upper or cooler end of desorber kiln 20 at delivery port 24. The desorber kiln is inclined so that its rotation causes the soil to move down
10 inside the kiln towards the burner end 20a. The heat from the burner 27 and from other exothermic reactions in the kiln, heats the soil, causing it to dry and desorb contained hydrocarbon contaminants.

The pre-heated combustion air in delivery duct 43a for desorber kiln 20 is divided into a first stream 25 for burner 27, and a second stream 26 of overbed
15 combustion air for effecting at least partial combustion of the desorbed hydrocarbon contaminants within the kiln. This combustion takes place both in close proximity to the soil bed in the kiln and in the hot gas stream passing along its interior. A suitable kiln for the desorber 20 is a high velocity burner such as the North American Hi Ram kiln burner, which provides a highly collimated stream of
20 high temperature gases along the centre of the kiln. Application of this burner type with the abovementioned admission of overbed air 26 ensures efficient and reliable ignition of hydrocarbons as they evolve from the soil as it progresses along the kiln, as depicted in Figure 2.

In the case of soils with high hydrocarbon contamination levels, energy
25 conservation will be secondary to controlling the LEL [please explain what this is] of the desorber off-gas. For this situation, the temperature of the desorber off-gases in duct 21 may be increased by controlling both the energy input to the desorber burner 27 and the amount of insitu combustion, to allow dilution of the desorber off-gases prior to gas cleaning. Controlled amounts of water may be
30 injected via sprays 29 located in duct 21 immediately downstream of the desorber kiln.

Remediated soil is recovered from desorber kiln at 28 at burner end 21a. The vapours exiting the desorber in duct 21 typically at around 275°C, and typically comprise 50% steam, 5% carbon dioxide, 44% nitrogen, and approximately 0.5-1% volatile hydrocarbons contaminants desorbed from the soil bed. As previously mentioned these vapours are cleaned of solid matter entrained from the kiln by cyclone 22 and/or bagfilter 23 before being pre-heated in heat exchanger stage 44 and injected into the thermal oxidiser via line 45.

The thermal oxidiser 30 is a 2-stage refractory-lined chamber comprising one or more burners to assist complete combustion of the hydrocarbon contaminated vapours from the thermal desorber. Typically the gases are heated and combusted at 1000-1200°C for approximately 1000ms. To minimise NO_x formation, and to decrease radiation to the front of the heat exchanger, the thermal oxidiser has two sequential combustion zones; i) the primary combustion zone (P) and, ii) the post-combustion zone (Q). Preheated combustion air, preheated contaminant vapours and auxiliary fuel are injected into the primary combustion zone using, preferably, but not restricted to, a nozzle mixing burner or burners 36. The air in the gas mixture is controlled to give an overall stoichiometric or slightly sub-stoichiometric combustion. Additional unheated combustion air is injected via ports around the periphery and at the entry to an afterburner 55 to give an overall excess oxygen in the hot gases of approximately 3% to ensure complete destruction of contaminant hydrocarbons, to provide additional turbulence, and to control the temperature of the gases entering the heat exchanger to typically between 950 and 1100°C. Gas temperatures above 1100°C will lead to decreased heat exchanger life.

Features of heat exchanger 40 include a wider tube spacing for the leading rows of tubes (typically three rows, to decrease convective heat transfer to these rows subject to high radiant heat fluxes), in bank M, and an energy dump valve 50. The combination of these features allows direct installation of heat exchanger 40 in the hot gas duct at the outlet of thermal oxidiser 30, without the need for radiation shields and without incurring excess metal temperatures. This saves weight and cost. Dump valve 50 allows venting of excess pre-heated air from the

leading tube bank M during operation. This dumping allows accurate control of the process energy balance with varying moisture and hydrocarbon contamination levels. In addition, this facility decreases manufacturing costs for the heat exchanger by allowing the use of lower alloy steels, and increases heat exchanger
5 life.

An optional feature to cope with even more extreme and variable operating conditions is to equip heat exchanger 40 with a bypass duct 55 and associated damper (either in one or both of the heat exchanger stages), to further increase the flexibility of the process to treat higher contaminated soils, and to improve the
10 operational safety of the heat exchanger stages.

The heat exchanger features, together with controlled combustion of hydrocarbon contaminants in desorber kiln 20, the use of nozzle mixing burners, and the 2-stage combustion in thermal oxidiser 30, combine to minimise overall energy consumption and therefore operating costs, greenhouse gas and NOx
15 emissions, and to increase throughput by minimising the gas volumes processed. These features also allow maintenance of metal temperatures above 500°C to minimise dioxin formation from PCB or salt-contaminated soils, but below 700°C to minimise exchanger metal oxidation and corrosion. In addition, the system design allows control such that the heat exchanger exit gas temperature is
20 maintained above 600°C to further minimise dioxin formation.

It is believed that, relative to no pre-heating, a total 55% reduction in energy consumption is achieved with the illustrated system by pre-heating all combustion air and the contaminant hydrocarbon vapours, at a level where combustion of hydrocarbon vapours in desorber kiln 20 is at about 20%.

25 The drawing also illustrates several modules for further off-gas treatment downstream of heat exchanger 40. These modules may be variously provided according to the characteristics of the contamination. For low chlorine containing soils, there is no further off-gas treatment and a short refractory line stack 60 is utilised. This approach minimises water and electrical energy consumption.

For high chlorine or PCB containing soils, where the risk of dioxin or hydrochloride containing gases is high, a scrubber section 62 is used to quench the off-gases and remove the chlorides. A preferred embodiment under these conditions is to allow a small bleed of hot off-gas (about 10%, depending on contamination levels) to bypass the scrubber on line 63 to provide sufficient re-heating of the scrubbed gas stream in the stack to prevent drooping or visible fumes. A proportion of the pre-heated combustion air may also be delivered to this bypass 63 by a delivery duct 43c.

For gases of intermediate chlorine compound content, a cold air quenching module is used, wherein a large volume of ambient air is injected at 65 into stack 60 to rapidly quench (within less than 750ms) the off-gases to below 200°C.

It will be understood that the invention disclosed and defined in this specification extends to all alternative combinations of two or more of the individual features mentioned or evident from the text or drawings. All of these different combinations constitute various alternative aspects of the invention.

It will also be understood that the term "comprises" (or its grammatical variants) as used in this specification is equivalent to the term "includes" and should not be taken as excluding the presence of other elements or features.

20 Innova Soil Technology Pty Ltd
By their Registered Patent Attorneys
Freehills Patent Attorneys

28 September 1998

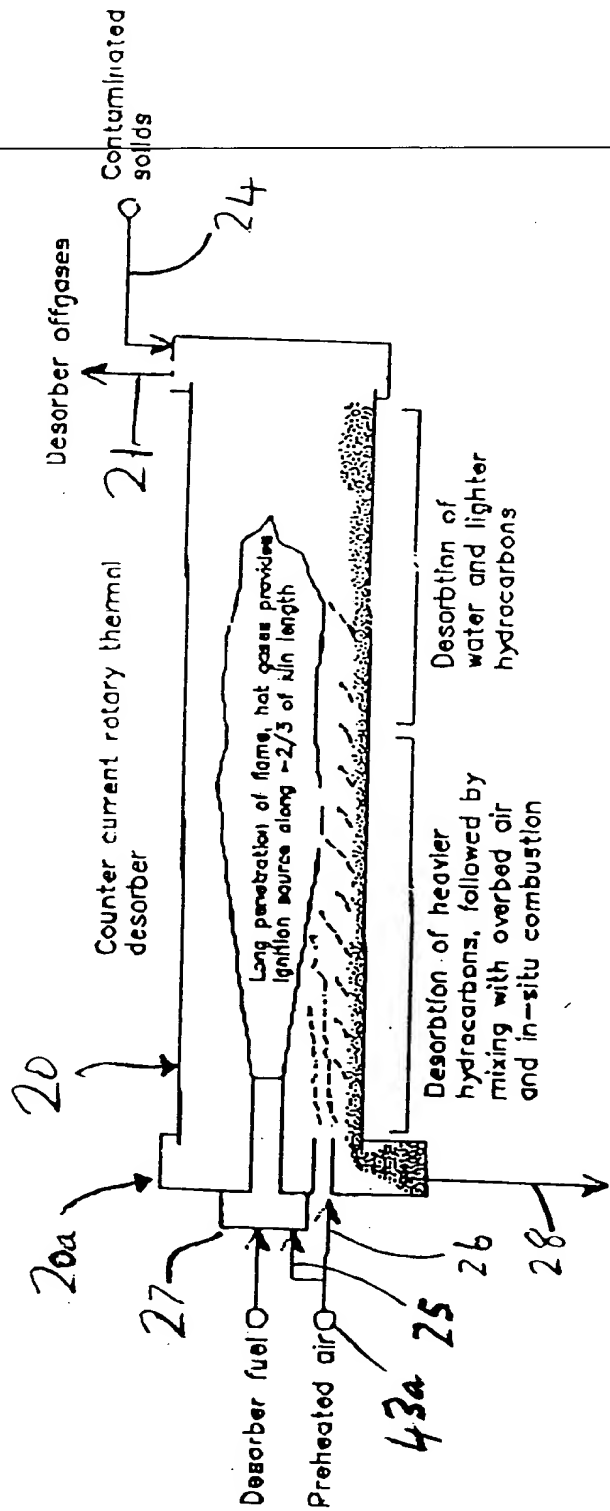


Fig 2

